LMDS is Feasible in the 40.5 - 42.5 GHz Band

1. Introduction and Summary

This paper investigates the feasibility of operating a Local Multipoint Distribution Service (LMDS) in the 40.5 - 42.5 GHz Band. Local Multipoint Distribution Service (LMDS) is primarily a wireless video distribution service intended to compete with wired cable service and direct broadcast satellite (DBS) service.

The initial proposal of Cellular Vision of New York, L.P. ("Suite 12") was to operate LMDS in the 28 GHz band (27.5 - 29.5 GHz). This paper shows that it is also feasible to operate LMDS in the 41 GHz band (40.5 - 42.5 GHz). It is feasible from a propagation standpoint and from an equipment standpoint.

The two potentially significant propagation effects in both the 28 GHz and the 41 GHz bands are atmospheric attenuation and rain attenuation. In Section 2 it is shown that the difference in the atmospheric attenuation between the 28 GHz and the 41 GHz bands is insignificant . Over a 3 mile link (4.8 km) the increased attenuation at 41 GHz is only 0.12 dB. The difference in rain attenuation between the 28 GHz and the 41 GHz bands also is not significant. In Section 2, it is shown that for identical hub antenna coverage, for identical transmit power, for identical cell size, and for identical subscriber antenna diameters the availability of an LMDS system operating in New York City changes from 99.9% in the 28 GHz band to 99.75% in the 41 GHz band. This is an inconsequential difference.

Section 3 shows the feasibility of an LMDS system operating in the 40.5 - 42.5 GHz band from an equipment standpoint. The implementation of LMDS and hence the required equipment depends on the type of services that are provided to the users and the system performance desired. During the 28 GHz Negotiating Rule Making Committee (NRMC) meetings, three significantly different LMDS systems were proposed by proponents. The difference in the implementation of these proposed LMDS systems at the 28 GHz band is far greater than the difference between implementation of any one LMDS system at 41 GHz rather than 28 GHz.

Section 3 demonstrates the feasibility of operating at the 41 GHz band by describing the implementation and the equipment for a video distribution system at this band that is expected to be operational in 1995. It is further shown that the costs associated with an LMDS system operating at the 41 GHz band are reasonable.

2. LMDS is Feasible in the 40.5 - 42.5 GHz Band from a Propagation Standpoint

The two potentially significant propagation effects in the 41 GHz band are atmospheric attenuation and rain attenuation. The following discussion demonstrates that the impact of these effects in the 41 GHz band is similar to that in the 28 GHz band. Thus, if LMDS is feasible in the 28 GHz band from a propagation perspective, then it is also feasible in the 41 GHz band.

Figure 2-1 shows that that the atmospheric attenuation due to water vapor is approximately the same at 41 GHz as it is at 28 GHz, a typical value is 0.06 dB/km. It also shows that the atmospheric attenuation due to oxygen is approximately 0.04 dB/km at 41 GHz versus 0.014 dB/km at 28 GHz. Over a 3 mile link (4.8 km) the increased attenuation at 41 GHz is 0.12 dB. This is an insignificant difference.

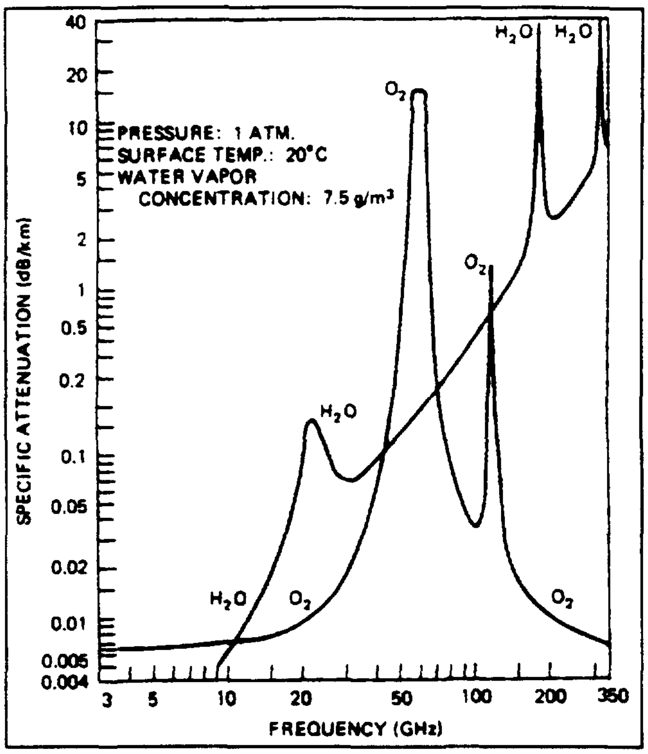

Figure 2-1. Atmospheric Attenuation by Oxygen and Water Vapor [1]

The CCIR rain model for terrestrial paths is given by [2]:

$$A = aR_{0.01}^{b} \frac{D}{1+0.045D} \times 0.12 \times p^{-(0.546+0.043\log p)}$$

where

A is rain attenuation (dB)

D is the distance between transmitter and the receiver (km)

p is the percentage rain unavailability

a and b are constants depend on frequency and polarization (Figure 2-2)

$R_{0.01}$ is the rain rate in (mm/hr) corresponding to p=0.01% (Figures 2-3 and 2-4)

Suite 12 has proposed to provide 99.90% rain availability in the 28 GHz band. The CCIR model shows that for identical hub antenna coverage, for identical transmit power, for identical cell size, and for identical subscriber antenna diameters, a 41 GHz LMDS System operating in New York City provides 99.75% rain availability. This is an inconsequential difference.

Frequency (GHz)	a_H	a_V	b_H	b_V
1	0.0000387	0.0000352	0.912	0.880
2	0.000154	0.000138	0.963	0.923
3	0.000650	0.000591	1.121	1.075
6	0.00175	0.00155	1.308	1.265
7	0.00301	0.00265	1.332	1.312
8	0.00454	0.00395	1.327	1.310
10	0.0101	0.00887	1.276	1.264
12	0.0188	0.0168	1.217	1.200
15	0.0367	0.0347	1.154	1.128
20	0.0751	0.0691	1.099	1.065
25	0.124	0.113	1.061	1.030
30	0.187	0.167	1.021	1.000
35	0.263	0.233	0.979	0.963
40	0.350	0.310	0.939	0.929
45	0.442	0.393	0.903	0.897
50	0.536	0.479	0.873	0.868
60	0.707	0.642	0.826	0.824
70	0.851	0.784	0.793	0.793
80	0.975	0.906	0.769	0.769
90	1.06	0.999	9.753	0.754
100	1.12	1.06	0.743	0.744
120	1.18	1.13	0.731	0.732
150	1.31	1.27	0.710	0.711
200	1.45	1.42	0.689	0.690
300	1.36	1.35	0.688	0.689
400	1.32	1.31	0.683	0.684

Figure 2-2 CCIR Rain Attenuation Model Parameters [2]

% Time	A	B	C	D	E	F	G	H	J	K	L	M	N	P
1.0	<0.5	1	2	3	1	2	3	2	8	2	2	4	5	12
0.3	1	2	3	5	3	4	7	4	13	6	7	11	15	34
0.1	2	3	5	8	6	8	12	10	20	12	15	22	35	65
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145
0.003	14	21	26	29	41	54	45	55	45	70	105	95	1409	200
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250

Figure 2-3 Yearly Average Rain Rates (mm/hr) [2]

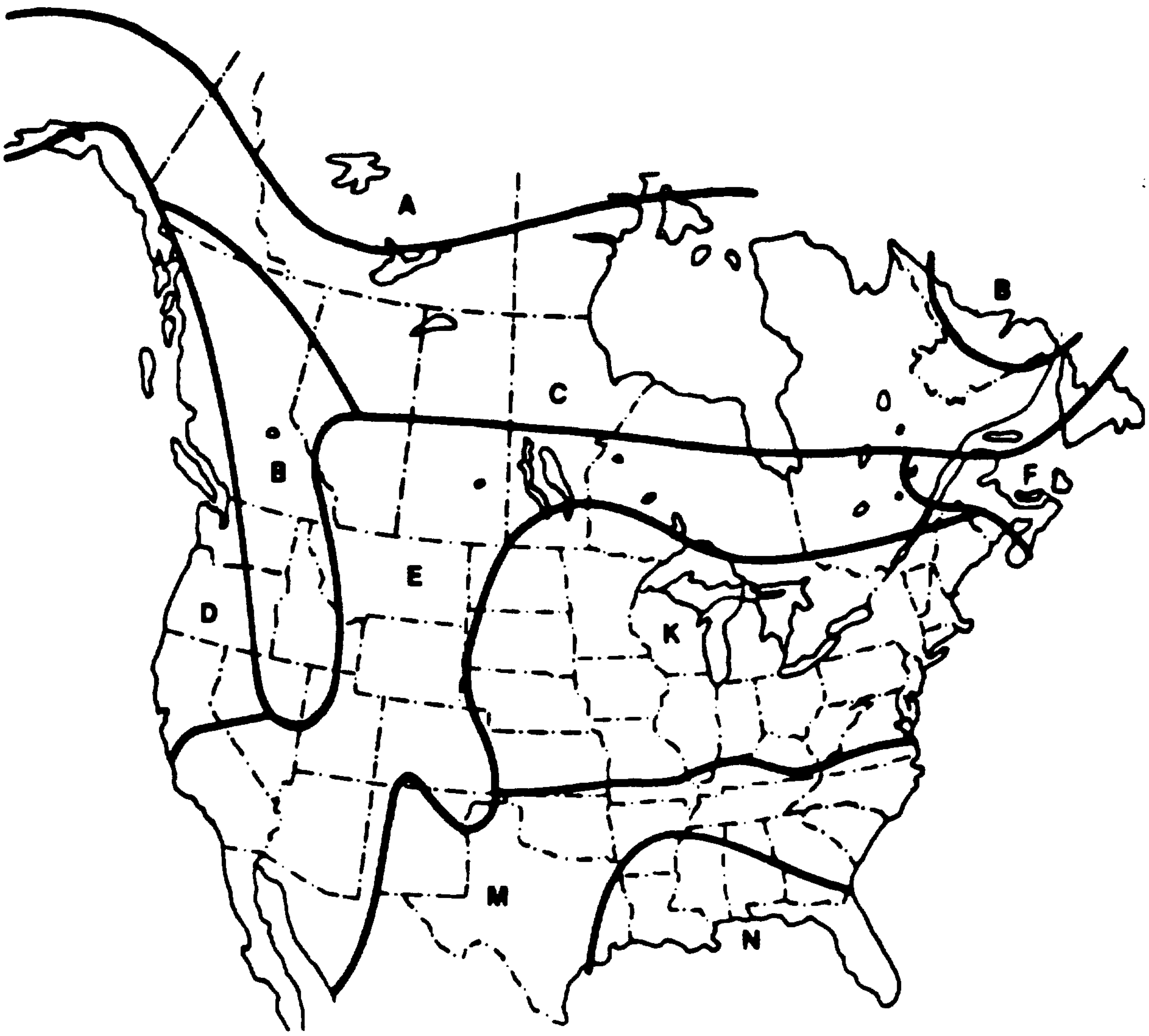

Figure 2-4: CCIR Rain Regions [2]

3. LMDS is Feasible in the 40.5 - 42.5 GHz Band from an Equipment Standpoint

The equipment differences between a 41 GHz LMDS system and a 28 GHz LMDS system are minimal. At the transmitter, the upconverter, power amplifier, and antenna are impacted. The transmitters (modulators and IF equipment), encoders, power supplies, equipment racks, site cost and equipment required to distribute programming to the hub are identical for both 41 GHz and 28 GHz operation. At the receiver, the antenna and low-noise block converter (LNB) are impacted. Thus, only the microwave components change. The other, more costly, elements of the LMDS system remain the same. Figure 3-1 shows a functional block diagram of a typical LMDS system with the impacted components identified.

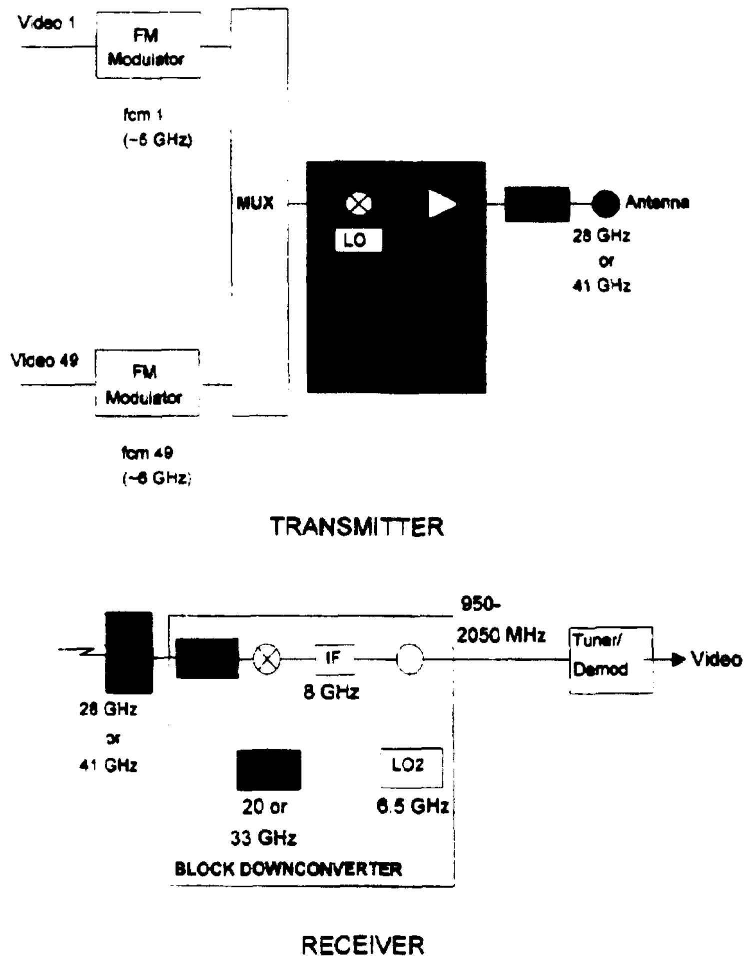

Figure 3-1: Typical Implementation of LMDS Transmitter and Receiver

The implementation of LMDS and hence the required equipment depends on the type of service that is provided to the users, the necessary technical and planning parameters, sharing criteria and licensing requirements. For example, during the 28 GHz Negotiating Rule Making Committee (NRMC) meetings, three LMDS systems were proposed by its proponents. These systems are different not only in their implementation, but also in the services that they would provide to the subscribers.

Clearly the implementation of these LMDS systems are significantly different from each other. For example, the average cell size proposed by one proponent is 3 miles with an omni directional antenna at the hub to reduce the cost of system implementation whereas another proponent's design uses 1 mile reduce cells and sector antennas to increase frequency reuse and data transfer capacity. The modulation techniques proposed by the proponents also included analog techniques such as AM and FM as well as digital modulation techniques such as QPSK and QAM. In short, the differences in the implementation of the proposed LMDS systems at 28 GHz, the required equipment, and the associated cost are far greater than the differences in implementation of one LMDS system at the two different frequencies of 28 GHz and 41 GHz.

The feasibility of implementing an LMDS system in the 41 GHz band, both from technical and economic points of view, has clearly been demonstrated in the United Kingdom. The Multipoint Video Distribution System (MVDS), as it is known in the UK, is an analog system that provides an alternative to cable for the delivery of video channels. The MVDS specifications were developed by a group of regulators, operators, and semiconductor, microwave component and antenna manufacturers who met between November, 1990 and January, 1993. The result of their work was the development of transmitter and transmit antenna performance specifications which were finalized in September 1993 as MPT 1550 [3], together with a companion report [4]. The decision to use the 40.5 to 42.5 GHz Band for the delivery of video signals was made in August of 1989. Since then, the CEPT [5] has adopted this band for MVDS in order to harmonize use across Europe, with the objective of providing economies of scale in equipment cost. The first MVDS system in the UK is being developed by Eurobell and it is expected to be operational in 1995. In 1994 another working group was formed in response to the notice of interest that was sent out by the Radio Communications Agency in the UK to develop requirements and specifications for a digital interactive MVDS.

The analog MVDS uses frequency modulation for the transmission of the video signals from the hub to the subscribers. The system concept takes into account the developments within the Fixed Satellite Service where Direct To Home (DTH) services are prevalent. It exploits the maximum commonality with DTH indoor receiver units by using them as a basis for MVDS receivers. This then defines the co-polar channel spacing interleaved with cross-polar channels from the other channel groups to be used in adjacent service areas.

For system planning purposes, MVDS adopts a quality criterion of carrier to noise ratio C/N = 12 dB for 1% of the Worst Month, equivalent to 99.7% availability, to provide a "satisfactory" picture grade (CCIR impairment grade 4). This availability is the same as that used in the design of Broadcast Satellite Service at 12 GHz. Using the typical transmitter, receiver and propagation parameters at 40 GHz for these quality and availability criteria results in service range of about 4 km (2.5 miles). The equipment specifications that can provide this service quality are described briefly below.

Transmitter - There are two options which can be used for RF transmitters at 41 GHz, traveling wave tube amplifiers (TWTAs) and solid state amplifiers. The TWTA approach requires frequency division multiplexing of the RF channels before the input to the device, with sufficient back-off to reduce intermodulation effects. The output feed then simply supplies all channels to a single antenna. The solid state amplifier approach requires a single device per channel, with each output feed directly to its own antenna, rather than via a complex and lossy combiner. The whole transmitter, waveguide, and antenna can be fabricated as one module. Both approaches can easily produce RF power output of 200 mW to 1 W per channel.

Transmit Antenna - Transmit antennas suitable for use in point-to-multipoint applications necessarily have wide beamwidth. MVDS studies have determined that a sector coverage antenna of 64°, having a gain of 15 dBi, is optimum for providing an essentially circular coverage area under rain faded conditions at the desired level of availability. The selection of the antenna sector beamwidth is based on the trade off between the difficulties in manufacturing wider beamwidth sectoral horns and the fact that more elliptical coverage areas are produced by lower beamwidths.

The advantage of the sector antenna is the more effective service planning and efficient frequency reuse compared to omnidirectional antennas, taking into account the benefit to be had from geographical terrain features, transmitter site availability and azimuthal discrimination between neighboring transmitters. It is however possible to use omnidirectional antennas.

Receiver Antenna and Low Noise Down Converter - The outdoor unit of the subscriber receiver is comprised of a 40 GHz antenna and a low noise block (LNB) down converter. The MVDS specification recommends that the antenna has a gain on order of 32 dBi and is assumed to be a parabolic reflector about 150 mm (6 inches) in diameter. The pointing accuracy needs to be maintained to within 1.5 degrees. To keep costs down, the 40 GHz LNB and antenna needs to be easily mass produced. Developments in High Electron Mobility Transistor (HEMT) technology allows the use of a monolithic low noise amplifier stage before the mixer. This makes achieving receiver noise figures of 6 dB economically feasible.

Receiver Indoor Unit - The design of the receiver indoor unit does depend on the frequency of the operation of the RF link at 28 GHz or 41 GHz. In the MVDS the use of the existing Fixed Satellite Service Direct-To-Home indoor receiver units has resulted in keeping the costs down.

Link Budget - A typical 40 GHz MVDS system link budget from previously discussed parameters is shown in Table 3-1.

Table 3-1: Link Budget for MVDS

MVDS LINK BUDGET		64° Sector Coverage Antenna
Transmitter power	(dBW)	-7
Transmit antenna gain	(dBi)	15
EIRP	(dBW)	8
KTB in 26 MHz	(dBW)	-129.7
Receiver noise figure	(dB)	9
C/N required	(dB)	12
Receive antenna gain	(dBi)	32
Receiver pointing error	(dB)	-2
Minimum received level	(dBW)	-138.7
Propagation loss to service boundary	(dB)	146.7
Gaseous absorption (0.14 dB/km)	(dB)	0.6
Rain attenuation (2.22 dB/km)	(dB)	9.1
Free space path loss	(dB)	137.0
Transmission distance to service boundary	(km)	4.1

References

[1] L.J., Ippolito, Jr., "Radiowave Propagation in Satellite Communications", Van Nostrand Reinhold, 1986, p. 32.

[2] L. J. Ippolito, Jr., "Propagation Effects Handbook for Satellite Systems Design", NASA Reference Publication 1082(04), Feb. 1989

[3] MPT 1550 Performance Specification for Analogue Multipoint Video Distribution Systems (MVDS) Transmitters and Transmit Antennas Operating in the Frequency Band 40.5 - 42.5 GHz. (Radiocommunication Agency).

[4] Report of the 40 GHz MVDS Working Group (Radiocommunications Agency).

[5] CEPT Recommendation T/R 52-01 E concerning the designation of a harmonised frequency band for MVDS in Europe

[6] Ian Clarke, "Microwave Video Distribution Systems - The 1994 Position," Phillips Microwave presentation to 40 GHz MVDS Working Group, 40GWG(94)16, 7 December 1994.

AFFIDAVIT OF MARK A. STURZA

I, Mark A. Sturza, being duly sworn, do depose and state as follows:

1. I am an electrical engineer specializing in Communication Systems Engineering, retained by Teledesic Corporation. Additional information concerning my engineering background and activities is shown in Attachment A hereto.

2. I prepared with Farzad Ghazvinian the Engineering Exhibit which is attached to the foregoing Comments of Teledesic Corporation in the matter of Amendment of Parts 2 and 15 of the Commission's Rules to Permit Use of Radio Frequencies Above 40 GHz for New Radio Applications. Except for those factual matters of which official notice may be taken or which are matters of public record, the statements made in the engineering exhibit are true, complete and correct to my personal knowledge.

Date: 27 Jan 1995

[signature]
MARK A. STURZA

Subscribed and sworn before me this 27TH day of JANUARY 1995

[signature]
NOTARY PUBLIC

My commission expires OCT 1, 1997

ANTHONY K. HILLS
COMM. #996381
NOTARY PUBLIC - CALIFORNIA
LOS ANGELES COUNTY
My Commission Exp. Oct. 1, 1997

The following is a supplement to the affidavit of Mark A. Sturza, 16161 Ventura Blvd. #815, Encino, CA 91436, Telephone Number (818) 907-1302.

I, Mark A. Sturza, received my BS in Applied Mathematics from the California Institute of Technology, (Pasadena, California), in 1977, my MSEE from the University of Southern California, (Los Angeles, California) in 1979, and my MBA from Pepperdine University, (Malibu, California) in 1985.

I have over 17 years of experience in the field of communications systems engineering.

From 1979 to the present I have been an independent consultant engaged in the design, development, and analysis of communications systems. My areas of specialization include: satellite communication systems, microwave radio systems, radio navigation systems, spread spectrum systems, and international and domestic regulatory support.

I was previously employed by Litton Aero Products as Director of Systems Engineering and as Director of GPS Development, by Magnavox Advanced Products and Systems Company as a Senior Engineer, and by Teledyne Systems Company as a Research Scientist.

I am a member of the Institute of Electrical and Electronics Engineers, a member of the Institute of Navigation, and a member of the American Institute of Aeronautics and Astronautics.

I have authored numerous technical papers in the areas of communications systems and of navigation systems that have been published in conference proceedings or technical journals.

I hold six U.S. patents and have several patents pending.

I have been an instructor at numerous short courses in the areas of communications systems and of radionavigation.

I have been an instructor in the School of Engineering at California State University, Northridge.

AFFIDAVIT OF FARZAD GHAZVINIAN

I, Farzad Ghazvinian, being duly sworn, do depose and state as follows:

1. I am an electrical engineer specializing in Communication Systems Engineering, retained by Teledesic Corporation. Additional information concerning my engineering background and activities is shown in Attachment A hereto.

2. I prepared with Mark A. Sturza the Engineering Exhibit which is attached to the foregoing Comments of Teledesic Corporation in the matter of Amendment of Parts 2 and 15 of the Commission's Rules to Permit Use of Radio Frequencies Above 40 GHz for New Radio Applications. Except for those factual matters of which official notice may be taken or which are matters of public record, the statements made in that engineering exhibit are true, complete and correct to my personal knowledge.

Date: 27 January 1995

F. Ghazvinian
FARZAD GHAZVINIAN

Subscribed and sworn before me this 27TH day of JANUARY 1995

Anthony K Hills
NOTARY PUBLIC

My commission expires OCT 1, 1997

ANTHONY K. HILLS
COMM. #996381
NOTARY PUBLIC - CALIFORNIA
LOS ANGELES COUNTY
My Commission Exp. Oct. 1, 1997

The following is a supplement to the affidavit of Dr. Farzad Ghazvinian, 5110 W. Goldleaf Circle, Suite 330, Los Angeles, CA 90056, Telephone Number (213) 293-3001

I, Farzad Ghazvinian, received my B.Sc. Degree in Electrical Engineering from London University (London, England) in 1975, my MSEE from University of California, Los Angeles in 1976, and my Ph.D. from University of Southern California (Los Angles, California) in 1981.

From 1981 to present, I have been employed by LinCom Corporation (Los Angeles, California) currently as Vice President and manager of Communication Systems Group.

I have supported NASA Goddard Space Flight Center on many communication system engineering efforts related to Tracking and Data Relay Satellite System (TDRSS). I have also performed many feasibility studies for advanced TDRSS concepts and applications in support of NASA space missions.

I have performed many analysis in support of NASA Johnson Space Flight Center, in connection with the design and performance evaluation of the communication systems of NASA's Space Station and Space Shuttle programs.

I have performed theoretical analysis and computer simulation to enhance the performance of ranging and synchronization systems for satellite and terrestrial networks.

I have performed feasibility study of a plan to implement a nationwide network of commercial broadcast radio stations for the purpose of emergency data communication.

I have received Public Service Group Achievement Award from NASA in recognition of my support in the development and application of Communication Link Analysis and Simulation System for NASA space programs.

I am co-author of many technical papers in the area of communication system analysis and design that has been published in conference proceedings or technical journals.

PUBLICATIONS

1. " Transition from NASA Space Communication Systems to Commercial Communication Products", Proceeding of Dual-Use Space Technology Transfer Conference, NASA JSC, Houston, February 1994.

2. " A Novel Approach to Model the Viterbi Decoded Error Sequence", Proceeding of Globecom '93, Houston, November 1993.

3. " Acquisition of the QPSK Demodulator in the Presence of Interference", Proceeding of MILCOM '90, Monterrey, October 1990.

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5. " Application of Expert System in CLASS", Proceedings of International Communication Conference ICC '88, Philadelphia, June 1988.

6. " Network synchronization ", with W.C. Lindsey, W.C. Hagmann, and K. Dessouky, Proceedings of IEEE, October 1985.

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13. " Dissemination of Time in a Digital Communication Network ", with W.C. Lindsey, Proceedings of National Radio Science Meeting, Boulder, January 1981.

George GILDER

TELECOSM

Ethersphere

New low earth orbit satellites mark as decisive a break in the history of space-based communications as the PC represented in the history of computing. Pay attention to much-maligned Teledesic. Backed by Craig McCaw and Bill Gates, it is the only LEO fully focused on serving computers.

"They'll be crowding the skies."

THUS STEVEN DORFMAN, president of telecommunications and space operations for GM Hughes—the colossus of the satellite industry—warned the world of a new peril in the skies. Planning to launch 840 satellites in low earth orbits, at an altitude of some 435 miles, were a gang of cellular phone jocks and computer hackers from Seattle going under the name of Teledesic. Led by Craig McCaw and Bill Gates, they were barging onto his turf and threatening to ruin the neighborhood.

You get the image of the heavens darkening and a new Ice Age looming as more and more of this low-orbit junk—including a total of some 1,200 satellites from Motorola's Iridium, Loral-Qualcomm's Globalstar and Teledesic, among other LEO projects—accumulates in the skies. Ultimately, from this point of view, you might imagine the clutter of LEOs eclipsing the geostationary orbit itself, the so-called Clarke belt, some 21,000 miles farther out. Named after science-fiction guru Arthur C. Clarke, the geostationary orbit is the girdle and firmament of the Hughes empire.

In an article in Wireless magazine in 1945, Clarke first predicted that satellites in orbit 22,282 miles (35,860 kilometers) above the equator, where the period of revolution is 24 hours, could maintain a constant elevation and angle from any point on Earth. In such a fixed orbit, a device could remain for decades, receiving signals from a transmitter on the earth and radiating them back across continents.

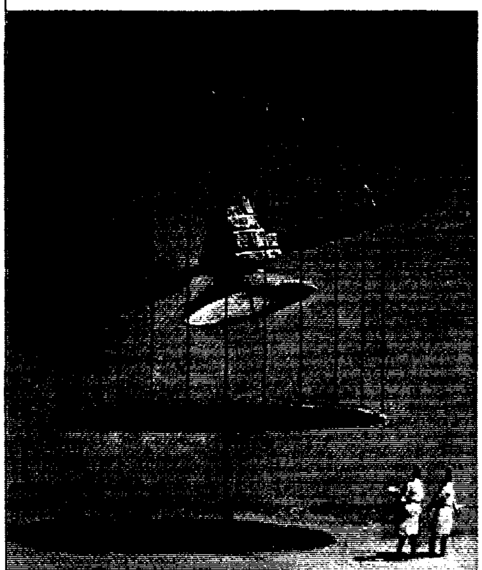
The Clarke orbit also posed a problem, however—the inverse square law for signal power. Signals in space attenuate in proportion to the square of the distance they travel. This means that communications with satellites 22,000 miles away typically require large antenna dishes (as much as 10 meters wide) or megawatts of focused beam power.

Now, however, a new satellite industry is emerging, based on gains in computer and microchip technology.

Illustrations: Chris McAllister

These advances allow the use of compact handsets with small smart antennas that can track low earth orbit satellites sweeping across the skies at a speed of 25,000 kilometers an hour at a variety of altitudes between 500 and 1,400 kilometers above the earth. Roughly 60 times nearer than geostationary satellites, LEOs find the inverse square law working in their favor, allowing them to offer far more capacity, cheaper and smaller antennas, or some combination of both. Breaking out of the Clarke orbit, these systems vastly expand the total available room for space-based communications gear.

It is indeed possible to "crowd" the Clarke belt—a relatively narrow swath at a single altitude directly above the equator. But even this swath does not become *physically* congested; collisions are no problem. The Clarke belt becomes crowded because the ability of antennas on the ground to discriminate among satellites is limited by the size of the antenna. Spaceway and Teledesic both plan to use the Ka band of frequencies, between 17 gigahertz and 30 gigahertz, or billions of cycles per second. In this band, reasonably sized antennas 66 centimeters wide can distinguish between geostationary satellites two degrees apart. That's some 800 miles in the Clarke belt. Thus no physical crowding. But it means that there are only a total of 180 Clarke slots for Ka band devices, including undesirable space over oceans.



LEOs, however, can be launched anywhere between the earth's atmosphere and a layer of intense radiation called the Van Allen Belt. The very concept of crowding becomes absurd in this 900-kilometer span of elevations for moving orbits that can be 500 meters apart or less. Thus the 21 proposed orbital planes of Teledesic occupy a total of 10 kilometers of altitude. At this rate, 70 or more Teledesic systems, comprising some 65,000 satellites, could comfortably fit in low earth orbits.

Nonetheless, it was clear that the LEOs, one way or another, were crowding Hughes. Hughes commands satellite systems or projects that compete with every one of the LEOs. Hughes responded to the threat of Teledesic by announcing the expansion of its Spaceway satellite system, then planned for North America alone, to cover the entire globe. Then, invoking the absolute priority currently granted geostationary systems, Hughes asked the Federal Communications Commission to block Teledesic entirely by assigning Spaceway the full five gigahertz of spectrum internationally available in the Ka band.

On May 27, Dorfman summoned the upstarts, Craig McCaw and Teledesic President Russell Daggatt, to Hughes headquarters in Los Angeles for a talk. Busy with Microsoft—the Redmond, Wash., company that in 1993 temporarily surpassed the market value of General Motors—Teledesic partner Bill Gates did not make the trip. But as the epitome of the personal computer industry, his presence haunted the scene.

Together with Spaceway chief Kevin McGrath, Dorfman set out to convince the Seattle venturers to give up their foolhardy scheme and instead join with Hughes in the nine satellites of Spaceway. Not only could Spaceway's nine satellites cover the entire globe with the same services that Teledesic's 840 satellites would provide, Spaceway could be expanded incrementally as demand emerged. Just loft another Hughes satellite. Indeed, Spaceway's ultimate system envisaged 17 satellites. With "every component proprietary to Hughes," as Dorfman said, the satellites only cost some $150 million apiece. By contrast, most of the $9 billion Teledesic system would have to be launched before global services could begin.

On May 27, Dorfman summoned the upstarts, McCaw and Daggatt, to Hughes headquarters in Los Angeles for a talk. Missing was Bill Gates of Microsoft, a company that in 1993 temporarily surpassed the market value of General Motors, Hughes's owner.

Nonetheless, the new LEOs marked as decisive a break in the history of space-based communications as the PC represented in the history of computing. Moreover, Teledesic would be the only LEO fully focused on serving computers—the first truly "global Internet," as McCaw's vice president Tom Alberg depicted it. It brings space communications at last into the age of ubiquitous microchip intelligence, and it brings the law of the microcosm into space communications.

If you enjoyed the New World of Wireless on the ground—with its fierce battles between communications standards, technical geniuses, giant companies, impetuous entrepreneurs and industrial politicians on three continents—you will relish the reprise hundreds and even thousands of miles up. Launching Teledesic, McCaw and

Gates were extending bandwidth abundance from earth into space. Observers, however, often did not like what they heard.

Bad Press for Two Billionaires

EVERY SO OFTEN, the media is taken by the notion of technology as a morality tale. In place of a gripping saga of unjustly obscure geniuses enriching the world by their heroic creativity in the teeth of uncomprehending bureaucrats and politicians, the media treat technology ventures as a school for scandal. We have mock exposés of computer hype, monopoly, vaporware, viruses, infoscams, netporn, securities "fraud" and deviously undocumented software calls. Pundits gabble endlessly about the gap yawning between the information rich and the information poor, thus consigning themselves undeniably, amid many yawns, to the latter category. While American market share climbs near 70% in computers, networks, software and leading-edge semiconductors, analysts furrow the brows of the Atlantic Monthly with tales of farseeing foreign teams, spearheaded by visionary government officials, capturing the markets of American cowboy capitalists. They spiel implausible yarns of tough-minded trade warriors prying open the jaws of Japan for Toys "R" Us, closing down vicious Korean vendors of low-priced dynamic RAMs, or blasting through barriers to U.S. telecom gear in the Tokyo-Osaka corridor, saving the day for Motorola's soon-to-be cobwebbed factories for analog cellular phones.

One of these sagas began early this year with two Seattle billionaires, McCaw and Gates, allegedly boarding McCaw's sleek yacht and going on an ego trip. With McCaw pitching in an early nickel, and the boat, and Gates hoisting his name as a sail, the two tycoons seemed to sweep away from the shores of rationality, as the media told it, into a sea of microwaves and arsenic. Spinning out Teledesic to build an information superhighway in the sky, they proposed to strew the heavens with 840 satellites, plus 84 spares. All would whirl around the world at a height of 700 kilometers (435 miles), using what they told the FCC would be some 500 million gallium arsenide microchips to issue frequencies between 20 and 60 gigahertz from some 180,000 phased-array antennas. The entire project seemed suffused with gigahertz and gigabucks. "We're bandwidth bulls," says Teledesic President Daggatt.

In case the hype of the sponsors failed to keep the system radiant and aloft, fueling it also would be a total of 12,000 batteries fed by thin film solar collectors stretching out behind the satellite "birds" in some 130 square kilometers of gossamer wings. Working at 4% efficiency, these cells would collectively generate 10 megawatts of power, enough to light a small city, but, so the critics said, insufficient to reach Seattle at microwave frequencies in the rain. (The Teledesic frequencies are readily absorbed by water in the air.) To manage the elaborate mesh of fast-packet communications among the satellites and ground terminals, the constellation would bear some 282,000 mips, or millions of instructions per second, of radiation-hard microprocessors and a trillion bytes or so of rad-hard RAM. In effect, Teledesic would be launching into space one of the world's largest and most expensive massively parallel computer systems.

At a mere $9 billion, to be put up by interested investors, Teledesic's lawyers told the FCC, the price would be a bargain for the U.S. and the world. (By contrast, current plans call for $15 billion just to lay fiber for interactive TV in California.) But former Motorola, now Kodak, chief George Fisher—fresh from pondering numbers for the apparently similar Iridium projects—suggested that $40 billion for Teledesic would be more like it. (Teledesic had the improbable result of making Iridium's 66-satellite plan, greeted in 1990 with much of the scorn now lavished on Teledesic, seem modest.) Just rocketing the 840 satellites into orbit was said to entail a successful launch every week for a year and a half at a time when hoisting satellites is still a precarious and sometime thing.

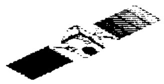
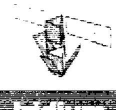
Even if Teledesic succeeded in getting the things up, so other scientists suggested, the satellites would then be impaled on some 7,000 pieces of space debris in the chosen orbits. In any case, so it was widely reported, 10% would fail every year, some tumbling out of orbit, others joining the whirl of litter, where they would fly ready to impale the remainder of the satellites and the remnants of the two billionaires' reputations.

Surely these sages know that by the year 2001, when the systems would be up and running, the world will be swimming in the bandwidth of "information superhighways." Why support this lavish launch of technology for a communications system that would be dwarfed by capabilities already demonstrated on the ground?

Summing up a near-consensus of critics, John Pike, director of the Federation of American Scientists' Space Policy Project, declared to the Wall Street Journal, "God save us. It's the stupidest thing I've ever heard of!" Provoking Pike may have been the origins of the multisatellite architecture in the Star Wars "brilliant pebbles" program. Teledesic's most amazing achievement to date has been to displace the Strategic Defense Initiative as Pike's peak example of stupidity.

While McCaw and Gates could be dismissed as tyros in the satellite field, Hughes is world champion. Since 1963, the company has put 107 communications satellites into orbit. With 19 in 1994, this year should be its biggest ever. In 1993, well before the Teledesic announcement, Dorfman announced the first version of Spaceway—a $660 million, two-satellite system offering voice, data and video services—as a contribution to "information superhighways."

In the midst of all the terrestrial uproar surrounding superhighwaymen Al Gore, John Malone of TCI, Raymond Smith of Bell Atlantic and scores of other telco and cable

	Globalstar	Iridium	Winner and Loser
Number of Satellites	48	66	More and smarter satellites means more capabilities for Iridium.
Cost of System	$1.8 billion	$3.4 billion	Globalstar cheap and efficient; Iridium gets little for the money.
Altitude	750 miles	483.3 miles	
Spectrum Request	Operates in "L" band (1.2 to 1.6 Gigahertz) and the "S" band (2 to 4 GHz). Can share with other CDMA systems.	"Give us the spectrum." TDMA requires exclusive allocation in "L" and "Ka" (20 to 30 GHz).	Globalstar's CDMA spectrum sharing ability is big winner.
Money Raised to Date	$275 million	$1 billion	Iridium big winner to date; but Globalstar needs far less.
Airtime Charge per Minute	30 cents	$3	Globalstar big winner.
Terminal Cost	$750	$2,500	Globalstar big winner.
Uses	Mobile voice, fax and E-mail	Mobile voice, fax and paging	Both systems target same market, but Iridium great in the Arctic.
Antenna Size	Three feet	Six feet	Globalstar more efficient.
Expandability	Capacity per beam times number of beams times frequency reuse factor. Globalstar can increase number of beams, number of satellites, and with CDMA reuse all frequencies everywhere.	Under TDMA, Iridium frequency reuse factor is 1/7 and airborne intelligence does not benefit from ground advances in microchips.	Globalstar is most expandable because of simple "bent pipe" architecture where most of system stays on the ground, and because of CDMA 100% frequency reuse.
Launch Weight	390 kg, 800 lbs	700 to 800 kg, 1,540 to 1,800 lbs	Globalstar lightest bird.
Spectrum Sharing	Yes	No	CDMA allows spectrum sharing; TDMA requires spectrum exclusivity, though can share by segmentation.
Modulation Scheme	CDMA	TDMA	CDMA allows superior performance for mobile voice and narrowband data communications, but awaits chip learning curve to yield cheap teleconferencing and computer video.
Spectrum Band Used	"L" band, "C" band (4-6 gHz), "S" band (2 to 4 GHz)	"L" & "S" bands.	Iridium uses "S" band for intersatellite links.
Regulatory Advantage	Spectrum sharing and use of ground infrastructure	Corporate clout at Motorola. Hurt by need for exclusive spectrum in crowded "L" band and by ground system bypass technology.	Globalstar can share spectrum and use local facilities.
Intersatellite Links	No	Yes	Globalstar's bent pipe is far cheaper and simpler. Iridium gets expense without bandwidth and is loser.
Rollout Date	1998	1998	Globalstar's simpler, more tested system may well be ready first.
Backers	Alcatel, France Telecom, Deutsche Aerospace, Vodafone and other local service operators.	Mitsui, Kyocera, DDI, Great Wall, Khrunichev, Mawarid, Lockheed, Raytheon	Iridium's backers have put up more money; Globalstar's backers are local exchange carriers that will offer the services.
Learning Curve	Simple technology with capabilities that will advance with Moore's Law, the progress of microchips and mobile computing	Iridium will also advance with Moore's Law, but since the intelligence of the system is in space, it cannot be readily upgraded before it is replaced.	Globalstar will advance more readily with the advance of the microcosm on the ground.
Time to Download Jurassic Park (2GB, MPEG 2)	6,945 hours @ 4.8 kbps	6,945 hours @ 4.8 kbps	Try Direct Broadcast Satellite (DBS).
Cost to Download Jurassic Park	$125,010	$1.25 million	Both of these are narrowband systems, ill-adapted to video or teleconferencing.
Time and Cost to Download Daily New York Times (1MB)	3.47 hours, $62.51	3.47 hours, $625.10	You may not want to get your Times this way either.
Bottom Line: Capacity and Cost			Globalstar commands 10% more capacity than Iridium at half the system cost.
Law of the Telecosm	Globalstar offers cheap bandwidth the ethernet of satellite systems. Suffers from initial lack of broadband capacity.	Iridium offers great concept but high-expense, low-bandwidth system.	Globalstar is the winner—more capacity, less cost, and spectrum sharing. Should Motorola join Teledesic.

magnates, however, no one paid much attention to Hughes.

Then came Gates and McCaw with Teledesic and claims of 20 million potential subscribers, two million simultaneous connections, billion-bit-per-second "gigalinks," bandwidth on demand and an array of other features, all advertised at a cost for Spaceway-type services nearly three times lower per bit per second. Everyone noticed Teledesic.

At the end of July, though, Hughes raised the stakes. With successful launches under way in China, Brazil and French Guiana to provide exclamation points, Hughes made a new submission to the FCC, extending Spaceway into a nine-satellite global system costing $3.2 billion. McGrath plausibly claimed it could be in place long before Teledesic and offer nearly all its functionality at a third of the price.

Already planned to be in place by 1998, however, were several other LEO projects, led by Motorola's Iridium and Loral-Qualcomm's Globalstar. As mobile phone projects, these systems could not readily offer service at T-1 data rates. But their sponsors promised availability for simple E-mail, faxes and paging.

By mid-1994, Motorola seemed to command the financial momentum. The company succeeded in raising some $800 million in equity investments from companies around the globe, including Lockheed and Raytheon (which would build the satellites), Great Wall of China and Khrunichev Enterprises of Russia (which together would launch a third of them), the Mawarid Group of Saudi Arabia (which pitched in $120 million) and Kyocera, Mitsui and DDI, which together put up another $120 million. (Kyocera will build the dual mode handsets for Japan and DDI will sell and service them.) On August 10, an Indian consortium purchased a 5% stake and a seat on the board for $38 million. Motorola claimed its share of the equity was dropping to 28.5%, well on the way to the company's final target of 15%. Motorola estimates that much of the additional $2 billion in the plan could come from debt securities and loans.

Iridium's attractions are impressive. It provides ubiquitous global phone service at a premium price with little or no dependence on local terrestrial facilities. In times of disaster or political crisis, or in places with sparse or unreliable local service, the system can route calls among the 66 satellites in space bypassing all infrastructure on the ground. For an elite of government officials and corporate figures operating in remote areas, the availability of Iridium should be worth the money. A bold and visionary concept when it emerged in 1987 from a team in the company's satellite systems engineering group, it endows many regions of the earth with voice and limited data communications for the first time. For example, it actually focuses on polar domains, such as parts of Siberia, poorly served by other satellite systems. Kazuo Inamori, the venerable chairman of Kyocera, also believes that Iridium will be popular in the 60% of territorial Japan not currently covered by cellular.

"Give Us Spectrum, Let Others Fight"

NONETHELESS, BEYOND the bold and ingenious concept (Daggatt calls Iridium "the real pioneer of LEOs"), the system suffers from technical flaws. Were it not for Globalstar, perhaps these flaws would not have become evident until after the 66 birds were aloft. A far simpler and cheaper solution, Globalstar uses 48 satellites with no links between them. Each functions as a "bent pipe" transponder, receiving signals from a phone on the ground and passing them back to any gateway within the satellite's 1,500-mile-wide footprint, linked to locally available telephone networks. Because Globalstar uses local phone systems rather than bypassing them, the system has been able to raise a total of some $300 million in support from Alcatel, France Telecom, Vodafone (serving the United Kingdom, Australia and Hong Kong), Airtouch-U S West, Hyundai and DACOM in Korea, Deutsche Aerospace and Alenia.

This amount may seem small beside the billion raised by Iridium. But Globalstar has capital costs (at $1.8 billion) one-half Iridium's, circuit costs one-third Iridium's, and terminal costs (at $750 each) one-fourth Iridium's. With no intelligence in space, Globalstar relies entirely on the advance of intelligent phones and portable computer devices on the ground; it is the Ethernet of satellite architectures. Costing one-half as much as Iridium, it will handle nearly 20 times more calls.

The advantages of Globalstar stem only partly from its avoidance of complex intersatellite connections and use of infrastructure already in place on the ground. More important is its avoidance of exclusive spectrum assignments. Originating several years before spread-spectrum technology was thoroughly tested for cellular phones, Iridium employs time division multiple access, an obsolescent system that requires exclusive command of spectrum but offers far less capacity than code division multiple access.

Like conventional cellular or radio transmissions that differentiate signals by time slot or frequency, TDMA sharply restricts the reuse of spectrum in nearby cells. By contrast, CDMA is a form of spread-spectrum communications that differentiates signals by a spreading code and allows the use of the same frequencies all the time, everywhere. Just as you can reduplicate wireline spectrum merely by laying another fiber, you can now manufacture new spectrum in the air merely by breaking large cells into smaller ones.

Among some six companies seeking low earth orbit satellite approval from the FCC in 1993, only Iridium used TDMA, requiring national and international bodies to pick it as a winner from the outset and assign it exclusive spectrum. By contrast, in a majority report issued to the FCC on April 6, 1993, CDMA companies in the U.S., including TRW, Loral-Qualcomm, Celsat and American Mobile Satellite, could all agree to share spectrum and let the market choose winners. A Motorola lawyer explained to Space News, "Give us the spectrum and let the others fight for whatever's left." In the face of alternatives with no need for exclusive spectrum allocations, Iridium could fly only if it offered radically superior performance or capacity. But TDMA dooms it to generally inferior performance and capacity.

Unlike TDMA systems, which can "see" only one satellite signal at a time, CDMA handsets have "path" diversity, using "rake receivers" that can combine a number of weak signals into an intelligible stream. Iridium and other TDMA systems compensate by using more power. But no practical amount of power can propel a satellite signal through a tin roof. And excess power means larger handsets or heavier satellites. Iridium satellites together use 80% more power than Globalstar's, yet employ antennas nearly twice as large and offer 18.2 times less capacity per unit area.

Teledesic also suffers from the use of TDMA. But Teledesic's T-1 capabilities would compensate with 100,000 times more bandwidth and with a bit error rate that can accommodate the new fiber standards such as SONET-ATM (synchronous optical network/asynchronous transfer mode), which send packets without retransmission. The issue is whether these features can justify the political, financial, and performance costs of using a modulation scheme—TDMA—that severely limits spectrum sharing and path diversity.

So what is this, another saga of hubris on the information super-highway—to go with the Raymond Smith–John Malone follies? Perhaps good new ideas are harder to come by as company revenues grow into the billions, and Gates and McCaw disinvest and diversify as fast as they can from their increasingly cumbrous vessels of wealth. Having

	Teledesic	Spaceway	Winner and Loser
Number of Satellites	840	Nine to 17	More satellites mean more potential bandwidth: Teledesic
Cost of System	$9 billion	$3.2 billion to $6 billion	Spaceway offers more for less with current technology
Altitude	435 miles	22,300 miles	Spaceway the mainframe of satellites, Teledesic into the microcosm.
Spectrum Request	One Gigahertz in Ka band (19-30 GHz)	2.5 GHz in Ka band up and down—entire international allocation for fixed satellite service.	Both Spaceway and Teledesic require exclusive spectrum. But Spaceway wants it all.
Money Raised to Date	$20 million	In-house project	Spaceway is a part of GM (Giant Money).
Airtime Charge per Minute	Four cents/minute for basic channel	$6 for 30-minute teleconference	Teledesic and Spaceway offer broadband at low price.
Terminal Cost	$1,000 for 64 kbps, 2 mbps $6,000-8,000	Under $1,000	
Uses	Fixed broadband service for computer data and video teleconferencing at up to T-1 rates (16 Kbps to 2.048 Mbps)	Fixed broadband service similar to Teledesic.	Teledesic and Spaceway focus on computer market, but Spaceway is crippled by half-second lag in links to Clarke belt at 22,300 miles.
Antenna Size	10 in.	26 in.	The higher the frequency the smaller the antenna. Teledesic wins in the Ka band because of low earth orbit.
Expandability	Will expand with the advance of microchip technology. Currently limited by orbital switching capacity.	Can be expanded with launch of more satellites, but limited by constaints of geostationary orbit.	Teledesic offers best expandability.
Launch Weight	1,700 lbs	3,785 lbs (spacecraft); launch weight 7,827 lbs.	Hughes wins the orbital shotput; Teledesic the lowest orbit.
Spectrum Sharing	No	No	TDMA requires spectrum exclusivity, though can share by segmentation
Modulation Scheme	FDMA/TDMA	FDMA/TDMA (unsettled)	
Spectrum Band Used	Ka band (19-30 gigahertz)	Ka band	Ka band allows smaller antennas, lower power, and more bandwidth.
Regulatory Advantage	Ability to conform to national boundaries and huge bandwidth benefits for Third World.	Geostationary satellites currently gain from exclusive spectrum priority over LEOs in International Telecommunications Union regs.	Hughes is in driver's seat under current ITU regulations, but may have overdone its demands.
Intersatellite Links	Yes	Yes	
Rollout Date	2001	1998	
Backers	Craig McCaw and Bill Gates	GM-Hughes	It's upstart billionaires vs. the Military Industrial Complex.
Learning Curve			Teledesic is a new technology riding Moore's Law; Spaceway a late iteration of a mature technology of geostationary satellites.
Time to Download Jurassic Park (2GB, MPEG 2)	16.3 minutes using E-1 line (2.042 Mbps), 16 seconds using Gigalink	21.59 hours using T-1 capability (1.544 Mbps)	Try Direct Broadcast Satellite
Cost to Download Jurassic Park	$20.00	$20.00	...or cable pay-per-view.
Time and Cost to Download Daily New York Times (1MB)	Five seconds, three cents	Seven seconds, cost not available	The Wall Street Journal would be cheaper and leave out the sports and PC.
Bottom Line: Capacity and Cost	Realistic capacity: 100,000 T-1s	Realistic capacity: 2,500 T-1s	Teledesic designed as ubiquitous broadband system competitive with ground infrastructure. Spaceway is a supplementary system inferior to ground service and more costly.
Law of the Telecosm	Teledesic is designed for the Telecosm. Ubiquitous computer connections.	Spaceway is mainframe of the satellite industry, today's champ but a maturing technology.	Teledesic the big winner; focuses on computer market and benefits from new computer technology.

recently passed the billion-dollar mark in his systematic process of disinvestment from Microsoft—he retains $8 billion or so—Gates at times seemed embarrassed by his link to this gigantic project. He told us it was too early to write about Teledesic.

No, the story is in fact more interesting. Impelled by the onrushing rise in the cost-effectiveness of individual chips compared to multichip systems, the Law of the Microcosm dictates decentralization of all information architectures. During the 1980s, this centrifuge struck the mainframe computer establishment of IBM. During the 1990s, the personal teleputer, summoning and shaping films and files of images from around the world, will collide with the centralized establishments of TV broadcasting. At the end of the century, Teledesic and the other LEOs will usher in the age of decentralization in space.

From this point of view, Gates's participation becomes more readily intelligible. Gates seems always to follow the microcosm wherever it leads. A vision of software for decentralized systems of personal computers informs everything Microsoft does.

In 1994, for example, Microsoft made an investment in Metricom, a wireless terrestrial system that supplies links of up to 56 kilobits per second to portable computers or personal digital assistants. Within cells, the devices can communicate directly with one another; outside the cell, Metricom routes its calls through an expandable mesh of nodes each the size of a shoebox and costing less than $1,000. Based on spread- spectrum technology, the system operates at power levels low enough to avoid the need for FCC licenses. Yet it can be expanded to metropolitan-area dimensions.

In many respects, Teledesic is Metricom in the sky. It is focused on computer communications. It routes packets by the most convenient path through a mesh of nodes. It is based on microprocessor technology. (Both Teledesic and Metricom plan to employ devices from Motorola's 68000 family.) As Gates explains the system: "Some functions are most efficiently performed by large numbers of small processors working together, rather than a few large ones." The entire new generation of low earth orbit satellite systems relies on this centrifugal force of the microcosm.

It was not supposed to happen this way. Just as Grosch's Law of the computer industry implied that computer power rose by the square of the cost, there was a similar law of the satellite industry that held satellite efficiency to be proportional to size. In a popular text, "Communications Satellite Systems," published in 1978, James Martin cited an AT&T study showing that just six satellites could carry all the long-distance traffic from the American continent; no fiber optics would be necessary. "The next major thrust in the space segment should capitalize on the economies of scale which today's technology offers," wrote Martin, urging creation of "massive hardware" as heavy as several tons and "immensely powerful satellites with large antennas beaming as much information as we are capable of using to our rooftops." Many satellite advocates, led by Arthur C. Clarke, viewed with impatient scorn the expensive terrestrial systems that somehow forestalled the manifest destiny of big birds to rule the world of communications.

Bringing the Microcosm to Space

IN 1994, THE BIG-BIRD DREAM still flourishes in Spaceway, the international consortium Inmarsat, and the new launch this summer of direct broadcast satellite technology by Hughes's DirecTV, Hubbard's USSB, TCI's Primestar, and Rupert Murdoch's imperial systems in Europe and Asia. Using centralized satellites in geosynchronous orbits, DBS is the ultimate broadcast medium, reaching billions of potential customers at the cost of reaching hundreds of thousands through cable-TV systems. But these geostationary satellite systems suffer from the same flaws as mainframes: sclerosis by centralization. At a time when customers want the choice, control, convenience and interactivity of computers, the big birds offer one-size-fits-all programming at specified times, with little ability to control the flow or interact with it.

The real showstopper in the long run, though, is a nagging half-second time delay for Clarke orbit signals. Bad enough for voice, a half-second is near eternity for computer communications; for the living-room and desktop supercomputers of 2001, a half-second delay would mean gigabytes of information to be stored in buffers. While companies across the country, from Intel to Digital Equipment, are rushing to market with cable modems to allow computer connections to CATV coax, geosatellites remain mostly computer-hostile. Even with the new digital cosmetics of DBS, geosynchronous satellites are a last vestige of centralization in a centrifugal world.

By contrast, Teledesic brings the microcosm to space. Rather than gaining economies of scale from using a few huge satellites, Teledesic gains economies of scale by launching as many small birds as possible. Based on Peter Huber's concept of a geodesic network—a mesh of peers equally spaced apart like the nodes in a geodesic dome—Teledesic is not a hierarchy but a heterarchy. Distributing the system responsibilities among 840 autonomous satellites diminishes the requirements, such as message throughput and power usage, for each one. Building redundancy into the entire constellation, rather than within each satellite, yields higher overall reliability, while reducing the complexity and price of each unit.

As Craig McCaw explains, "At a certain point, redundant systems create more complexity and weight than they are worth. Rather than having each satellite a 747 in the sky with triply redundant systems, we have hundreds of satellites that offer self-redundancy." Eschewing the Hughes philosophy of "every component proprietary to Hughes," Teledesic will manufacture and launch a large number of satellite peers, using off-the-shelf parts whenever possible. This approach also provides economies of scale that, according to a study by brilliant pebbles contractor Martin Marietta, could lower unit costs by a factor of one hundred or more.

Just as microcosmic technology uses infinitesimal low-powered transistors and puts them so close together that they work faster than large high-powered transistors, Teledesic satellites follow the rules of low and slow. Rather than one big powerful bird spraying signals across continents, Teledesic offers 840, programmably targetable at small localities. Just 435 miles out, the delay is measured in milliseconds rather than half-seconds.

The total computing power and wattage of the constellation seems large, as is needed to sustain a volume of some two million connections at a time, four times Spaceway's capacity. But with other link features equal, between 1,226 and 3,545 times more power is needed to communicate with a geostationary satellite than with a LEO.

Perhaps most important, unlike Iridium, TRW's Odyssey, and Globalstar, Teledesic from the outset has targeted the fastest-growing market of the future: communications for the world's 125 million PCs, now growing some 20% a year. And Teledesic has correctly chosen the technology needed to extend computer networks globally—broadband low earth orbit satellites. The real issue is not the future of Teledesic but the future of Iridium.

In the short run Iridium's voice services cannot compete with Globalstar's cheaper and more robust CDMA system. But in the long run Iridium could be trumped by Teledesic. Although Teledesic has no such plans, the incremental cost of incorporating an "L" band transceiver in Teledesic, to perform the Iridium functions for voice, would be just 10% of Teledesic's total outlays, or less than $1 billion (compared with the $3.4 billion initial

And the Winner Is . . .

Globalstar is the easy winner for current offering of mobile phone services under a CDMA regime of spectrum sharing. But Teledesic can add phone services to its broadband computer system. Over time, Teledesic's 840 satellites will outperform Globalstar's 48. Big question: When will microchip technology advance enough to allow broadband applications over CDMA? When that happens, Globalstar has a shot at the grand prize. Iridium is both too expensive to compete in mobile phones and too narrowband for data. Today's champ Spaceway is maturing. Big winner for the next decade is...Teledesic.

capital costs of Iridium). But 840 linked satellites could offer far more cost-effective service than Iridium's 66.

Iridium's dilemma is that the complexities and costs of its ingenious mesh of intersatellite links and switches can be justified only by offering broadband computer services. Yet Iridium is a doggedly narrowband system focused on voice.

Iridium eventually will have to adopt Teledesic's broadband logic and architecture. To protect its global lead in wireless communications and equipment, Motorola should join with Teledesic now, rather than later. Working with Lockheed, Motorola is making impressive gains in satellite-manufacturing technology. Supplying both handsets and space gear for computer networks, Motorola could turn its huge investment of time, money and prestige in Iridium into a dramatic global coup in wireless computer services. As part of a broadband system, Iridium could still become a superb brand name for Motorola. But persisting in a narrowband strategy in the name of avoiding Teledesic's larger initial costs, Motorola's executives will end up inflicting serious strategic costs on the company.

Most of the famous objections to Teledesic are based on ignorance or misinformation. Launch anxieties spring chiefly from the GEO experience. LEOs are 60 times nearer and between a tenth and a third the weight. Teledesic satellites are designed to be hoisted in groups of eight or more. From Great Wall in China to Khrunichev in Russia, companies around the world will soon be competing to supply low-cost launching facilities for the system. Orbital Sciences, an entrepreneurial dervish near Washington's Dulles Airport with some $190 million in revenues, has developed a low-cost method for lofting groups of LEOs from an adapted Lockheed 1011 Tristar.

Other fears are similarly fallacious. Teledesic will work fine in the rain because the high minimum vertical angle (40 degrees) of its satellite links from the ground reduces the portion of the path exposed to water to a manageable level. By contrast, geostationary satellites must operate at eight degrees, passing the signal through a long span of atmosphere. Made of tough new composite materials, Teledesic satellites will endure the kind of debris found in space mostly unscathed. The solar arrays can accept holes without significantly damaging overall performance. All in all, Teledesic's designers expect the birds to remain in orbit for an average of ten years. With most of its key technologies plummeting in price along with the rest of electronic components, the system may well cost even less and perform better than its business plan promises or George Fisher speculates.

Indeed, widely charged with reckless technological presumption, the designers of Teledesic in fact seem recklessly cautious in their assumptions about the rate of microchip progress. For example, their dismissal of CDMA assumes that the high speed of the spreading code functions—requiring digital signal processors that race at least 100 times the data rate—pushes cheap T-1 performance far into the future. Yet in early 1995, Texas Instruments will ship its multimedia video processor, a marvel that combines four 64-bit DSPs, a 32-bit RISC CPU, 50 kilobytes of on-chip memory, a floating-point unit and a 64-bit direct memory access controller all on one chip. This device now performs two billion operations per second and, with an upgrade from 35 megahertz to 50 megahertz clock rate, soon will perform three billion. The estimated cost in 1995 is around $400, or a stunning $133 per bop (current Pentiums charge three times as much for 100 mips). Five years from now, when Teledesic gets serious, that kind of one-chip computing power can implement CDMA for broadband data without any cost penalty. Future generations of CDMA systems may be able to offer, at a dramatically lower price, the same broadband services in *mobile* applications that Teledesic now promises for fixed services only.

Assuming that Teledesic meets the CDMA challenge, the other fear is that terrestrial systems will capture enough of the market to render Teledesic unprofitable. This fear, however, can come true only if governments delay this supremely beneficial system well into the next century.

Unlike the competition, satellite systems can provide global coverage at once. Whether for $9 billion or $90 billion, no terrestrial system will cover the entire world, or even the entire U.S., within decades of Teledesic. As soon as it is deployed, it will profoundly change the geography and topography of the globe. Suddenly the most remote rural redoubt, beach, or mountain will command computer communications comparable to urban corporations today. The system can make teleconferencing, telecommuting, telemedicine, and teleschooling possible anywhere. Gone will be the differences among regions in access to cultural and information resources. People will be able to live and work where they want rather than where corporations locate them.

This change transforms the dimensions of the world as decisively as trains, planes, automobiles, phones and TVs changed them in previous eras. It will extend "universal service" more dramatically than any new law can.

Moreover, Teledesic can eliminate the need to cross-subsidize rural customers. Determining the cost of wireline services are the parameters of population density and distance from the central office. Rural customers now cost between 10 and 30 times as much to serve with wires as urban customers do. Teledesic will bring near-broadband capabilities to everyone in the world at the same price.

Most important, this expansion of the communications frontier will foster the very economic development that will fuel the demand for the service. Today, it does not pay to bring telecommunications to poor countries that might benefit most. Teledesic and other satellite services break the bottleneck of development. Simultaneously opening the entire world, it enriches every nation with new capital exceeding the fruits of all the foreign aid programs of the era.

Teledesic is a venture worthy of McCaw and Gates. In its impact on the world, it may even rival the Herculean contributions of its sponsors in cellular and software. The issue is not the technology or the commitment of the principals. The issue is the readiness of the U.S. government to accommodate this venture. Before Teledesic can be approved internationally, it will have to attain a license from the FCC in the U.S. It has taken four years to approve Iridium. It took 30 years to approve cellular. How long will it take to approve Teledesic?

Currently Teledesic, Iridium and Globalstar face several political obstacles. The International Telecommunications Union's Radio Regulation 2613 gives GEOs absolute priority over LEOs. For Spaceway, Hughes is now demanding an exclusive license for the full five gigahertz available in the Ka-band worldwide, leaving no room for Teledesic or any other Ka-band LEO. Under current law, Hughes or other geo systems could usurp any LEO that was launched.

LEOs are a major American innovation. The U.S. government should take the lead now in spearheading a change in the regulations to accommodate LEOs. This is no minor matter. As the dimensions and promise of Teledesic loom more starkly, the Japanese or Europeans are certain to make similar proposals. "When they do," Craig McCaw predicts, "they will immediately have their government on board. They will be able to go to the ITU right away. My greatest fear is that we will have the technology all ready, and foreign companies will beat us out because they can get their governments in line."

The U.S. government was on board for Apollo 25 years ago and the U.S. won the first space race. This space race is just as important, but the government is treating it as some sleepy-time infrastructure project. In fact, it is the information superhighway going global and ubiquitous. It is the ultimate promise of the information age, says McCaw.

Sustaining the U.S. Lead in Technology

McCaw explains: "It'll mean ecological disaster if China mimics what we did—building more and more urban towers and filling them up with people who queue up every day on turnpikes into the city, emitting fumes into the air, and then building new towers and new highways when you want to move the company, and then digging up the highways to install new wires."

McCaw waves toward the window, out at Lake Washington. "Look at that floating bridge. It took $1.5 billion to cross Lake Washington, then it got busted in a storm. Cross this lake, any lake, any ocean in the world with broadband wireless. That's the promise of Teledesic. All you do is to reconfigure the communications in software at zero incremental cost. No wires for the final connections. It's what we do in Hong Kong and Shanghai, where everyone uses a cellular phone."

President Clinton, Vice President Gore and other members of the administration continually ask what they can do for technology. One thing they can do is vastly streamline the process for approval of communications projects. At the moment, Congress is determined to retain bureaucratic dominance over the most dynamic enterprise and technology in the world economy—what they like to term the information superhighway. They see it as a possible source of congressional power, campaign finance, employment and pelf, like the Baby Bells today or like existing construction projects. Rather than turn telecom into a vast porkbellied poverty program, however, the administration should deregulate the field. Communications companies must be permitted to compete and collaborate wherever the technology leads.

Whether the administration knows it or not, these technologies are its greatest political asset. The high-tech industries unleashed in the 1980s by venture capital and junk bonds are now the prime fuel of the economy of the 1990s. Comprising perhaps 60% of incremental GDP and 48% of exports, the momentous upsurge of computers and communications is even compensating for the mistakes of the Bush and Clinton regimes and making plausible Clinton's continuing claims of economic success. But now Clinton, Gore and FCC Chairman Reed Hundt must make a choice. If they want to maintain this redemptive U.S. lead in technology, they must be willing to forge new alliances in Congress to get the politicians and bureaucrats out of the way of the future. A good start would be to open the floodgates for the global onrush of low earth orbit satellites dedicated to computer communications. If they do, they can help make the world, as McCaw's Alberg puts it, "a truly global Internet in an ever-expanding ethersphere."